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## INVESTIGATION OF PROCESS INDUCED RESIDUAL STRESSES AND DEFORMATIONS FOR INDUSTRIALLY PULTRUDED PARTS HAVING UD AND CFM LAYERS

Ismet Baran<sup>1\*</sup>, Jesper H. Hattel<sup>1</sup>, Remko Akkerman<sup>2</sup>

<sup>1</sup>Technical University of Denmark, Department of Mechanical Engineering, Kgs. Lyngby, Denmark

<sup>2</sup>University of Twente, Faculty of Engineering Technology, Enschede, The Netherlands

\*Presenter e-mail: [isbar@mek.dtu.dk](mailto:isbar@mek.dtu.dk)

### Abstract

Pultrusion process is one of the most effective manufacturing techniques for production of composite materials having constant cross-sectional area. Pultruded composite profiles are getting increasingly popular in construction industry as well as in wind energy due to their high strength-to-weight ratio, low maintenance cost and high corrosion resistance. Recently, pultruded profiles are foreseen to have potential for the replacement of some of the conventional materials used in the construction industry. An example of this is the increased application of structural pultruded profiles for bridge constructions. A consequence of the enhanced usage of pultruded profiles requires detailed understanding of the mechanical behavior as well as the failure mechanism of the profile. Therefore, in order to improve the product quality and the degree of reliability of the pultruded products, a series of processing design challenges must be tackled such as process induced residual stresses and distortions.

Industrially pultruded parts generally contain the combination of unidirectional (UD) rovings with continuous filament mat (CFM) layers which have different thermal and mechanical properties, i.e. the former has transversely isotropic properties, and on the other hand the latter has the quasi-isotropic properties. At present, no contribution has been given in the literature regarding the thermo-chemical-mechanical behavior of the industrially pultruded products during processing. In the present study, thermo-chemical-mechanical simulation of the pultrusion process is carried out by means of finite element method (FEM). A pultruded I-beam, L-shaped and rectangular hollow profiles having UD and CFM layers are considered in the simulations. The process induced residual distortions (warpage formation for the rectangular hollow profile and spring-in generation for the L-shaped profile) and stresses (internal stresses in the I-beam profile) together with the temperature and degree of cure fields are predicted. A three dimensional (3D) transient thermo-chemical model is sequentially coupled with a 2D quasi static generalized plane strain mechanical model for the pultrusion process using the FEM. The proposed 3D/2D approach is found to be efficient and computationally fast for the calculation of the residual stresses and distortions together with the temperature and the degree of cure distributions. The predicted deformation pattern for the rectangular hollow at the end of the process is found to agree quite well with the one for the real pultruded part in a commercial pultrusion company (see Fig. 1). These unwanted residual distortions may lead to not meeting the desired geometrical tolerances e.g. warpage of pultruded window frames and hollow profiles as well as spring-in of L-shaped profiles, etc. The residual stresses might play a vital role for the load carrying parts such as pultruded wind turbine blade reinforcements, structural profiles in the construction industry etc. Therefore, the present work is very much of interest to the pultrusion processing community.

**Keywords:** Pultrusion, residual/internal stresses, residual deformations, spring-in, warpage, curing.

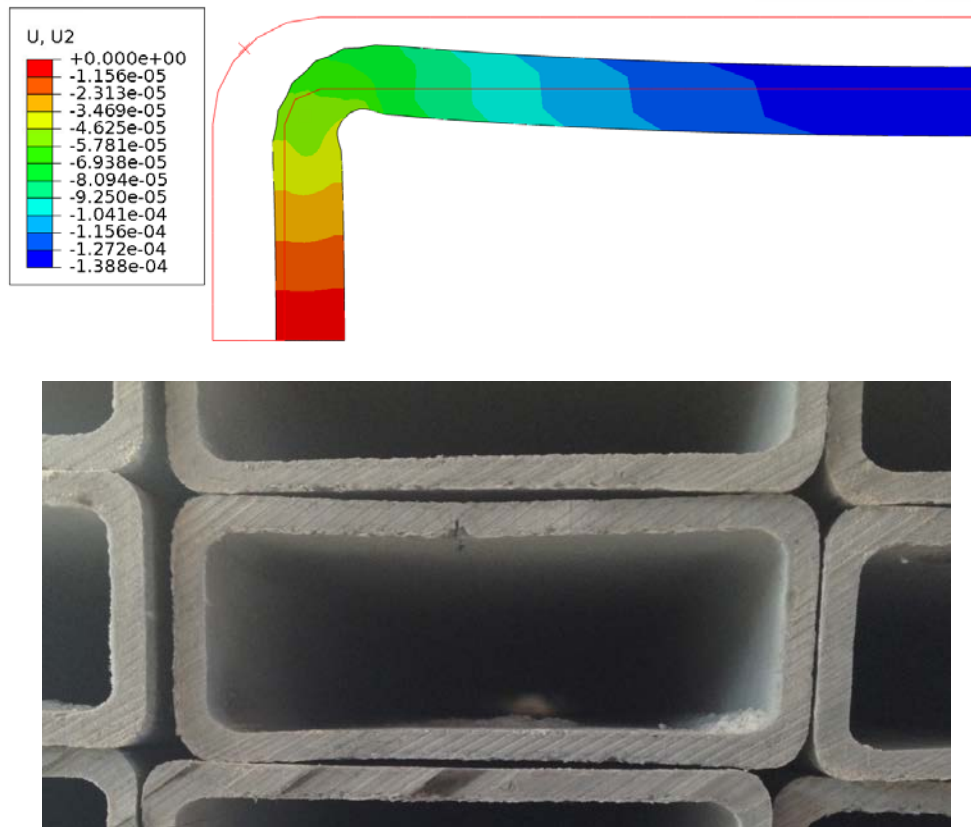


Figure 1. The predicted residual deformation (warpage) pattern for the rectangular hollow profile at the end of the pultrusion process (*top*). The corresponding actual deformed pultruded profile (*bottom*). The units are in m.